While townetting during the last few days about the North Cape, we have had some large hauls of Copepoda; and it occurred to us last night, while watching the midnight sun off the entrance to the Lyngen Fjord, that one gathering might be spared from the preserving bottle and devoted to the saucepan. We put out one of the smaller townets (3½ feet long, mouth 1 foot in diameter) from 11.40 p.m. to midnight, the ship going dead slow, and traversing in all, say, a mile and a half during the 20 minutes. The net when hauled in contained about three tablespoonfuls of a large red Copepod (*Calanus finmarchicus*, I think), apparently a pure gathering—what Haeckel would call a monotonic plankton. We conveyed our material at once to the galley, washed it in a fine colander, boiled it for a few minutes with butter, salt, and pepper, poured it into a dish, covered it with a thin layer of melted butter, set it in ice to cool and stiffen, had it this morning for breakfast on thin bread-and-butter, and found it most excellent. The taste is less pronounced than that of shrimps, and has more the flavour of lobster. Our 20 minutes' haul of the small net through a mile or two of sea made, when cooked in butter, a dishful which was shared by eight people, and would probably have formed, with biscuit or bread, a nourishing meal for one person. It would apparently, in these seas, be easy to gather very large quantities, which might be preserved in tins or dishes, like potted shrimps. W. A. HERDMAN.

S.Y. *Argo*, Tromsö, Norway, July 13.

Are Seedlings of *Hemerocallis fulva* specially Variable?

I SHALL be grateful to any of your readers who will write and let me know their experiences as to the variability of seedlings of *Hemerocallis fulva*, or who will raise it from seed in fair quantity, and kindly communicate to me their results, which shall be duly acknowledged.

My reason is this: there is in the formation of the pollen in this plant a peculiarity which, according to Weismann's views, should lead to exceptional variability in the seedlings; but, so far as I know, we have no evidence on the subject.

MARCUS M. HARTOG.

Royal University, Dublin, July 9.

The Green Sandpiper.

ON Sunday last, July 12, I saw flying round a large pool in Essex, a specimen of the *green sandpiper*. It flew leisurely round the pool, and seemed as if it were not far from its summer home. I think, therefore, that the bird must be nesting in the county, and probably in the neighbourhood.

Can any of your correspondents inform me whether the nest has been found anywhere, in recent years, in England?

ARGYLL.

Argyll Lodge, Kensington, July 17.

LIQUIDS AND GASES.[1]

ALMOST exactly twenty years ago, on June 2, 1871, Dr. Andrews, of Belfast, delivered a lecture to the members of the Royal Institution in this hall, on "The Continuity of the Gaseous and the Liquid States of Matter." He showed in that lecture an experiment which I had best describe in his own words:—

"Take, for example, a given volume of carbonic acid at 50° C., or at a higher temperature, and expose it to increasing pressure till 150 atmospheres have been reached. In the process, its volume will steadily diminish as the pressure augments; and no sudden diminution of volume, without the application of external pressure, will occur at any stage of it. When the full pressure has been applied, let the temperature be allowed to fall, until the carbonic acid has reached the ordinary temperature of the atmosphere. During the whole of this operation, no break of continuity has occurred. It begins with a gas, and by a series of gradual changes, presenting nowhere any abrupt alteration of volume, or sudden evolution of heat, it ends with a liquid.

"For convenience, the process has been divided into two stages—the compression of the carbonic acid, and its subsequent cooling. But these operations might have been performed simultaneously, if care were taken so to arrange the application of the pressure and the rate of cooling, that the pressure should not be less than 76 atmospheres when the carbonic acid had cooled to 31°."

I am able, through the kindness of Dr. Letts, Dr. Andrews' successor at Belfast, to show you this experiment, with the identical piece of apparatus used on the occasion of the lecture twenty years ago.

I must ask you to spend some time to-night in considering this remarkable behaviour; and, in order to obtain a correct idea of what occurs, it is well to begin with a study of gases, not, as in the case you have just seen, exposed to high pressures, but under pressures not differing greatly from that of the atmosphere, and at temperatures which can be exactly regulated and measured. To many here to-night, such a study is unnecessary, owing to its familiarity; but I will ask such of my audience to excuse me, in order that I may tell my story from the beginning.

Generally speaking, a gas, when compressed, decreases in volume to an amount equal to that by which its pressure is raised, provided its temperature be kept constant. This was discovered by Robert Boyle in 1660; in 1661 he presented to the Royal Society a Latin translation of his book, "Touching the Spring of the Air and its Effects." His words are:—

"'Tis evident, that as common air, when reduced to half its natural extent, obtained a spring about twice as forcible as it had before; so the air, being thus compressed, being further crowded into half this narrow room, obtained a spring as strong again as that it last had, and consequently four times as strong as that of common air."

To illustrate this, and to show how such relations may be expressed by a curve, I will ask your attention to this model. We have a piston, fitting a long horizontal glass tube. It confines air under the pressure of the atmosphere—that is, some 15 pounds on each square inch of area of the piston. The pressure is supposed to be registered by the height of the liquid in the vertical tube. On increasing the volume of the air, so as to double it, the pressure is decreased to half its original amount. On decreasing the volume to half its original amount, the pressure is doubled. On again halving, the pressure is again doubled. Thus you see a curve may be traced, in which the relation of volume to pressure is exhibited. Such a curve, it may be remarked incidentally, is termed an hyperbola.

We can repeat Boyle's experiment by pouring mercury into the open limb of this tube containing a measured amount of air; on causing the level of the mercury in the open limb to stand 30 inches (that is, the height of the barometer) higher in the open limb than the closed limb, the pressure of the atmosphere is doubled, and the volume is halved. And on trebling the pressure of the atmosphere the volume is reduced to one-third of its original amount; and, on adding other 30 inches of mercury, the volume of the air is now one-quarter of that which it originally occupied.

It must be remembered that here the temperature is kept constant; that it is the temperature of the surrounding atmosphere.

Let us next examine the behaviour of a gas when its temperature is altered, when it becomes hotter. This tube contains a gas—air—confined at atmospheric pressure by mercury, in a tube surrounded by a jacket or mantle of glass, and the vapour of boiling water can be blown into the space between the mantle and the tube containing the air, so as to heat the tube to 100°, the temperature of the steam. The temperature of the room is 17° C., and the gas occupies 290 divisions of the scale. On blowing in steam, the gas expands, and on again equalizing pressure, it stands at 373 divisions of the scale. The gas has thus expanded from 290 to 373 divisions, *i.e.* its volume has increased by 83 divisions; and the temperature has risen from 17° to 100°, *i.e.* through 83°. This law of the expansion of gases was discovered almost simultaneously by Dalton and Gay-Lussac in 1801; it usually goes by the name of Gay-Lussac's law. Now, if we do not allow the volume of the gas to increase, we shall find that the pressure will increase, in the same proportion that the volume would have increased had the gas been allowed to expand, the pressure having been kept constant. To decrease the volume of the gas, then, according to Boyle's law, will require a higher initial pressure; and if we were to represent the results by a curve, we should get an hyperbola, as before, but one lying higher as regards pressures. And so we should get a set of hyperbolas for higher and higher temperatures.

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[1] Lecture delivered by Prof. W. Ramsay, F.R.S., at the Royal Institution, on Friday, May 8.

We have experimented up to the present with air—a mixture of two gases, oxygen and nitrogen; and the boiling-points of both of these elements lie at very low temperatures: – 184° and – 193°·1 respectively. The ordinary atmospheric temperature lies a long way above the boiling-points of liquid oxygen and liquid nitrogen at the ordinary atmospheric pressure. But it is open to us to study a gas, which, at the ordinary atmospheric temperature and pressure, exists in the liquid state; and for this purpose I shall choose water-gas. In order that it may be a gas at ordinary atmospheric pressure, however, we must heat it to a temperature above 100° C., its boiling-point. This tube contains water-gas at a temperature of 105° C.; it is under ordinary pressure, for the mercury columns are at the same level in both the tubes and in this reservoir, which communicates with the lower end of the tube by means of the india-rubber tubing. The temperature 105° is maintained by the vapour of chlorobenzene, boiling in the bulb sealed to the jacket, at a pressure lower than that of the atmosphere.

Let us now examine the effect of increasing pressure. On raising the reservoir, the volume of the gas is diminished, as usual; and nearly in the ratio given by Boyle's law; that is, the volume decreases in the same proportion as the pressure increases. But a change is soon observed; the pressure soon ceases to rise; the distance between the mercury in the reservoir and that in the tube remains constant, and the gas is now condensing to liquid. The pressure continues constant during this change; and it is only when all the water-gas has condensed to liquid water that the pressure again rises. After all gas is condensed, an enormous increase of pressure is necessary to cause any measurable decrease in volume, for liquid water scarcely yields to pressure, and in such a tube as this, no measurements could be attempted with success.

Representing this diagrammatically, the right-hand part of the curve represents the compression of the gas; and the curve is, as before, nearly a hyperbola. Then comes a break, and great decrease in volume occurs without rise of pressure, represented by a horizontal line; the substance in the tube here consists of water-gas in presence of water; the vertical, or nearly vertical line represents the sudden and great rise of pressure, where liquid water is being slightly compressed. The pressure registered by the horizontal line is termed the "vapour-pressure" of water. If, now, the temperature were raised to 110°, we should have a greater initial volume for the water-gas; it is compressible by rise of the mercury as before, the relation of pressure to volume being, as before, represented on the diagram as an approximate hyperbola; and as before, condensation occurs when volume is sufficiently reduced, but this time at a higher pressure. We have again a horizontal portion, representing the pressure of water-gas at 110° in contact with liquid water; again, a sharp angle where all gaseous water is condensed, and again a very steep curve, almost a straight line, representing the slight decrease of volume of water produced by a great increase of pressure. And we should have similar lines for 120°, 130°, 140°, 150°, and for all temperatures within certain limits. Such lines are called isothermal lines, or shortly "isothermals," or lines of equal temperature, and represent the relations of pressure to volume for different temperatures.

Dr. Andrews made similar measurements of the relations between the pressures and volumes of carbon dioxide, at pressures much higher than those I have shown you for water. But I prefer to speak to you about similar results obtained by Prof. Sydney Young and myself with ether, because Dr. Andrews was unable to work with carbon dioxide free from air, and that influenced his results. For example, you see that the meeting-points of his hyperbolic curves with the straight lines of vapour-pressures are curves, and not angles; that is caused by the presence of about 1 part of air in 500 parts of carbon dioxide; also the condensation of gas was not perfect, for he obtained curves at the points of change from a mixture of liquid and gas to liquid. We, however, were more easily able to fill a tube with ether free from air, and you will notice that the points I have referred to are angles, not curves.

Let me first direct your attention to the shapes of the curves in the diagram. As the temperature rises, the vapour-pressure lines lie at higher and higher pressures, and the lines themselves become shorter and shorter. And finally, at the temperature 31° for carbon dioxide, and at 195° for ether, there ceases to be a horizontal portion at all; or rather, the curve touches the horizontal at one point in its course. That point corresponds to a definite temperature, 195° for ether; to a definite pressure, 27 metres of mercury, or 35·6 atmospheres; and to a definite volume, 4·06 cubic centimetres per gram of ether. At that point the ether is not liquid, and it is not gas; it is a homogeneous substance. At that temperature ether has the appearance of a blue mist; the striæ mentioned by Dr. Andrews, and by other observers, are the result of unequal heating, one portion of the substance being liquid, and another gas. You see the appearance of this state on the screen.

When a gas is compressed, it is heated. Work is done on the gas, and its temperature rises. If I compress the air in this syringe forcibly, its temperature rises so high that I can set a piece of tinder on fire, and by its help explode a little gunpowder. If the ether at its critical point be compressed by screwing in the screw, it is somewhat warmed, and the blue cloud disappears. Conversely, if it is expanded a little by unscrewing the screw, and increasing its volume, it is cooled, and a dense mist is seen, accompanied by a shower of ether rain. This is seen as a black fog on the screen.

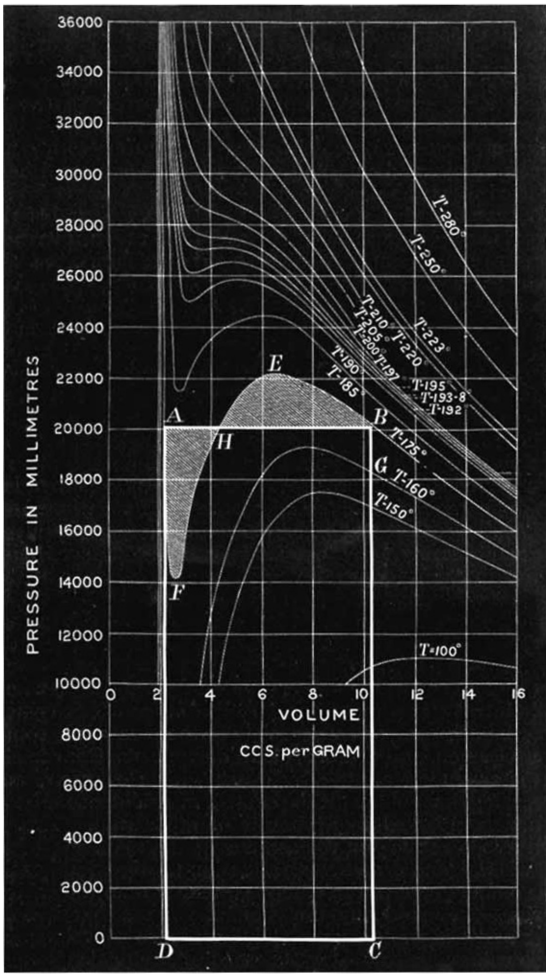
I wish also to direct your attention to what happens if the volume given to the ether is greater than the critical volume—on increasing the volume, you see that it boils away and evaporates completely; and also what happens if the volume be somewhat less than the critical volume—it then expands as liquid, and completely fills the tube. It is only at the critical volume and temperature that the ether exists in the state of blue cloud, and has its critical pressure. If the volume be too great, the pressure is below the critical pressure; if too small, the pressure is higher than the critical pressure.

Still one more point before we dismiss this experiment. At a temperature some degrees below the critical temperature, the meniscus, *i.e.* the surface of the liquid, is curved. It has a skin on its surface; its molecules, as Lord Rayleigh has recently explained in this room, attract one another, and it exhibits surface-tension. Raise the temperature, and the meniscus grows flatter; raise it further, and it is nearly flat, and almost invisible; at the critical temperature it disappears, having first become quite flat. Surface-tension, therefore, disappears at the critical point.

A liquid would no longer rise in a narrow capillary tube; it would stand at the same level outside and inside.

It was suggested by Prof. James Thomson, and by Prof. Clausius about the same time, that if the ideal state of things were to exist, the passage from the liquid to the gaseous state should be a continuous one, not merely at and above the critical point, but below that temperature. And it was suggested that the curves, shown in the figure, instead of breaking into the straight line of vapour-pressure, should continue sinuously. Let us see what this conception would involve.

On decreasing the volume of a gas, it should not liquefy at the point marked B on the diagram, but should still decrease in volume on increase of pressure. This decrease should continue until the point E is reached. The anomalous state of matters should then occur, that a decrease in volume should be accompanied by a decrease of pressure. In order to lessen volume, the gas must be exposed to a continually diminishing pressure. But such a condition of matter is of its nature unstable, and has never been realized. After volume has been decreased to a certain point, F, decrease of volume is again attended by increase of pressure, and the last part of the curve is continuous with the realizable curve representing the compression of the liquid, above D.



Dr. Sydney Young and I succeeded, by a method which I shall briefly describe, in mapping the actual position of the unrealizable portions of the curve. They have the form pictured in this figure. The rise from the gaseous state is a gradual one; but the fall from the liquid state is abrupt.

Consider the volume 14 cubic centimetres per gram on the figure. The equi-volume vertical line cuts the isothermal lines for the temperatures 175°, 180°, 185°, 190°, and so on, at certain definite pressures, which may be read from a properly-constructed diagram. We can map the course of lines of equal volume, of which the instance given is one, using temperatures as ordinates and pressures as abscissæ. We can thus find the relations of temperature to pressure for certain definite volumes, which we may select to suit our convenience—say, 2 c.c. per gram; 3, 4, 5, 6, and so on. Now, all such lines are straight—that is, the relation of pressure to temperature, at constant volume, is one of the simplest; pressure is a linear function of temperature. Expressed mathematically—

$$p = bt - a,$$

where b and a are constants, depending on the volume chosen, and varying with each volume. But a straight line may be extrapolated without error; and so, having found values for a and b for such a volume as 6 c.c. per gram, by help of experiments at temperatures higher than 195°, it is possible by extrapolation to obtain the pressures corresponding to temperatures below the critical point 195° by simple means. But below that temperature the substance at volume 6 is in practice partly liquid and partly gas. Yet it is possible by such means to ascertain the relations of pressure to temperature for the *unrealizable portion* of the state of a liquid—that is, we can deduce the pressure and temperature corresponding to a continuous change from liquid to gas. And in this manner the sinuous lines on the figure have been constructed.

It is possible to realize experimentally certain portions of such continuous curves. If we condense all gaseous ether, and, when the tube is completely filled with liquid, carefully reduce pressure, the pressure may be lowered considerably below the vapour-pressure corresponding to the temperature of ebullition, without any change further than the slight expansion of the liquid resulting from the reduction of pressure—an expansion too small to be seen with this apparatus. But on still further reducing pressure, sudden ebullition occurs, and a portion of the liquid suddenly changes into gas, while the pressure rises quickly to the vapour-pressure corresponding to the temperature. If we are successful in expelling all air or gas from the ether in filling the tube, a considerable portion of this curve can be experimentally realized.

The first notice of this appearance, or rather of one owing its existence to a precisely similar cause, is due to Hooke, the celebrated contemporary of Boyle. It is noted in the account of the proceedings of the Royal Society on November 6, 1672, that "Mr. Hooke read a discourse of his, containing his thoughts of the experiment of the quicksilver's standing top-full, and far above the height of 29 inches; together with some experiments made by him, in order to determine the cause of this strange phenomenon. He was ordered to prepare those experiments for the view of the Society." And on November 13 "the experiment for the high suspension of quicksilver being called for, it was found that it had failed. It was ordered that thicker glasses should be provided for the next meeting."

There can be no doubt that this behaviour is caused by the attraction of the molecules of the liquid for each other. And if the temperature be sufficiently low, the pressure may be so reduced that it becomes negative—that is, until the liquid is exposed to a strain or pull, as is the mercury. This has been experimentally realized by M. Berthelot and by Mr. Worthington, the latter of whom has succeeded in straining alcohol at the ordinary temperature with a pull equivalent to a negative pressure of 25 atmospheres, by completely filling a bulb with alcohol, and then cooling it. The alcohol in contracting strains the bulb inwards; and finally, when the tension becomes very great, parts from the glass with a sharp "click."

To realize a portion of the other bend of the curve, an experiment has been devised by Mr. John Aitken. It is as follows:—If air—that is, space, for the air plays a secondary part—saturated with moisture be cooled, the moisture will not deposit unless there are dust-particles on which condensation can take place. It is not at first evident how this corresponds to the compressing of a gas without condensation. But a glance at the figure will render the matter plain. Consider the isothermal 175° for ether, at the point marked A. If it were possible to lower the temperature to 160°, without condensation, keeping volume constant, pressure would fall, and the gas would then be in the state represented on the isothermal line 160°, at G: that is, it would be in the same condition as if it had been compressed without condensation.

You saw that a gas, or a liquid, is heated by compression; a piece of tinder was set on fire by the heat evolved on compressing air. You saw that condensation of ether was brought about by diminution of pressure—that is, it was cooled. Now, if air be suddenly expanded, it will do work against atmospheric pressure, and will cool itself. This globe contains air; but the air has been filtered carefully through cotton-wool, with the object of excluding dust-particles. It is saturated with moisture. On taking a stroke of the pump, so as to exhaust the air in the globe, no change is evident; no condensation has occurred, although the air has been so cooled that the moisture should condense, were it possible. On repeating the operation with the same globe, after admitting dusty air—ordinary air from this room—a slight fog is produced, and, owing to the light behind, a circular rainbow is seen; a slight shower of rain has taken place. There are comparatively few dust particles, because only a little dusty air has been admitted. On again repeating, the fog is denser; there are more particles on which moisture may condense.

One point more, and I have done. Work is measured by the distance or height through which a weight can be raised against the force of gravity. The British unit of work is a foot-pound—that is, a pound raised through one foot; that of the metric system is one gram raised through one centimetre. If a pound be raised through two feet, twice as much work is done as that of raising a pound through one foot, and an amount equal to that of raising two pounds through one foot. The measure of work is therefore the weight multiplied by the distance through which it is raised. When a gas expands against pressure, it does work. The gas may be supposed to be confined in a vertical tube, and to propel a piston upwards, against the pressure of the atmosphere. If such a tube has a sectional area of one square centimetre, the gas in expanding a centimetre up the tube lifts a weight of nearly 1000 grams through one centimetre; for the pressure of the atmosphere on a square centimetre of surface is nearly 1000 grams—that is, it does 1000 units of work, or ergs. So the work done by a gas in expanding is measured by the change of volume multiplied by the pressure. On the figure, the change of volume is measured horizontally, the change of pressure vertically. Hence the work done is equivalent to the area ABCD on the figure.

If liquid, as it exists at A, change to gas as it exists at B, the substance changes its volume, and may be made to do work. This is familiar in the steam-engine, where work is done by water, expanding to steam and so increasing its volume. The pressure does not alter during this change of volume, if sufficient heat be supplied, hence the work done during such a change is given by the rectangular area.

Suppose that a man is conveying a trunk up to the first story of a house, he may do it in two (or, perhaps, a greater number of) ways. He may put a ladder up to the drawing-room window, shoulder his trunk, and deposit it directly on the first floor. Or he may go down the area stairs, pass through the kitchen, up the kitchen stairs, up the first flight, up the second flight, and down again to the first story. The end result is the same; and he does the same amount of work in both cases, so far as conveying the weight to a given height is concerned; because in going down-stairs he has actually allowed work to be done on him, by the descent of the weight.

Now, the liquid in expanding to gas begins at a definite volume; it evaporates gradually to gas without altering pressure, heat being, of course, communicated to it during the change, else it would cool itself; and it finally ends as gas. It increases its volume by a definite amount at a definite pressure, and so does a definite amount of work; this work might be utilized in driving an engine.

But if it pass continuously from liquid to gas, the starting-point and the end point are both the same as before. An equal amount of work has been done. But it has been done by going down the area stair, as it were, and over the round I described before.

It is clear that a less amount of work has been done on the left-hand side of the figure than was done before; and a greater amount on the right-hand side; and if I have made my meaning clear, you will see that as much less has been done on the one side as more has been done on the other—that is, that the area of the figure BEH must be equal to that of the figure AFH. Dr. Young and I have tried this experimentally—that is, by measuring the calculated areas; and we found them to be equal.

This can be shown to you easily by a simple device—namely, taking them out and weighing them. As this diagram is an exact representation of the results of our experiments with ether, the device can be put in practice. We can detach these areas which are cut out in tin, and place one in each of this pair of scales, and they balance. The fact that a number of areas thus measured gave the theoretical results of itself furnishes a strong support of the justice of the conclusions we drew as regards the forms of these curves.

To attempt to explain the reasons of this behaviour would take more time than can be given to-night; moreover, to tell the truth, we do not know them. But we have at least partial knowledge; and we may hope that investigations at present being carried out by Prof. Tait may give us a clear idea of the nature of the matter, and of the forces which act on it, and with which it acts, during the continuous change from gas to liquid.

EXPERIMENTAL RESEARCHES ON MECHANICAL FLIGHT.

THE following is a translation of a communication made by Prof. S. P. Langley to the Paris Academy of Sciences on July 13:—

I have been carrying out some researches intimately connected with the subject of mechanical flight, the results of which appear to me to be worthy of attention. They will be published shortly in detail in a memoir. Meanwhile I wish to state the principal conclusions arrived at.

In this memoir I do not pretend to develop an art of mechanical flight; but I demonstrate that, with motors having the same weights as those actually constructed, we possess at present the necessary force for sustaining, with very rapid motion, heavy bodies in the air; for example, inclined planes more than a thousand times denser than the medium in which they move.

Further, from the point of view of these experiments and